Arctic Upper Ocean Studies\

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LONG-TERM GOALS

My goals are to investigate and understand the turbulent transfer of momentum, heat, salt, and other scalar contaminants in naturally occurring boundary layers of the ocean, and to apply this knowledge to understanding air-ice-ocean interaction in polar regions.

OBJECTIVES

Objectives of the project include (i) gathering and analyzing turbulence data from the ocean boundary layer (OBL) under sea ice; (ii) developing techniques, including both new instrumentation and analysis methods, for determining turbulent fluxes in the boundary layer; (iii) combining measurements and theory (including numerical modeling) for concise descriptions of turbulent boundary layer scales; and (iv) using the results to develop parameterizations of important boundary layer processes for large scale numerical models of the sea ice/upper ocean system.

APPROACH

I have developed systems for measuring vertical turbulent fluxes of momentum, heat, and salt in the ocean boundary layer under drifting sea ice by direct covariance of the respective quantities with vertical velocity. Several methods of measuring current have been utilized, but I have found the most productive to be orthogonal triads of small mechanical current meters mounted near Sea-Bird temperature and conductivity sensors in turbulence instrument clusters (TICs) mounted at several levels on rigid masts. The masts may then be lowered to any level within the upper 120 m of the ocean. The turbulence measurements, nearly unique for ocean boundary layer environments, are then used to determine properties and scales of OBL turbulence.

WORK COMPLETED

If FY98, I completed the following:

(i) Deployed the SHEBA Continuous Time Series (CTS) mast in October, 1997, and followed up with “horizontal variability” studies using a portable mast system at other three sites under different ice types near the SHEBA main station.

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(ii) Described anomalous freshening of the mixed layer observed during the SHEBA deployment relative to conditions during the 1975 AIDJEX project in the same vicinity at the Workshop on Polar Change in November, then wrote a note on the comparison, co-authored with SHEBA ocean physics PIs (McPhee et al., 1998a).

(iii) Completed a manuscript (with co-authors) on heat flux during winter in the Weddell Sea based on turbulence and remote buoy measurements made during the ANZFLUX project in 1994 (McPhee et al., 1998b).

(iv) Returned to SHEBA during March, 1998, for more horizontal homogeneity studies in collaboration with T. Stanton. As station chief scientist, I oversaw relocation of the ocean off-ship site after significant ice deformation.

(v) Assembled a "lead-edge" turbulence study to complement J. Morison's AUV summer lead study at SHEBA. The field work was done by a student in close cooperation with Morison's group.
(vi) Presented suggestions for parameterization of ocean fluxes in large scale ice models at the PIPS 3.0 workshop in Monterey.

(vii) Began analysis of the extensive SHEBA and SCICEX 98 data sets.

RESULTS

The SHEBA CTS turbulence mast operated with few gaps from 8 Oct 97 to 27 Sep 98. Combined with the upper ocean profiling instrument and acoustic doppler sonars deployed by the Scripps group, the data represent by far the longest and best record of upper ocean physical properties ever collected in polar regions. Several unexpected results have already emerged from the SHEBA program. First, we found during deployment near the center of the Beaufort Gyre in the Canada Basin, that the ice was much thinner and the mixed layer much less saline than expected. Compared with AIDJEX results from 1975, there was evidence for excessive melting during the 1997 summer suggesting the possibility of major changes in the perennial ice pack (McPhee et al., 1998a). The anomalously fresh mixed layer persisted in the SHEBA measurements until mid-January, 1998, reaching salinity values less than 26.5 in the western Canada Basin. After that, mixed layer salinity increased rapidly once the station began drifting into shallower water west of the Northwind Escarpment.

Although water just below the mixed layer was much warmer than expected in the fall of 1997, entrainment of heat into the mixed layer during fall and early winter was quite small (Fig. 1A), as a result of the strong salinity gradient at the base of the mixed layer. After the station drifted out of the fresh water pool over the Canada Basin, stratification was less intense, and ocean heat flux during storms increased substantially. An extreme example is shown in Fig. 1B, from data taken when the SHEBA CTS mast was in the wake of a newly formed pressure ridge. While the large value shown in Fig. 1B was not representative of the entire region, it was common for heat flux during storms in February and March to exceed 30 W m^-2, in contrast to November and December when heat flux rarely exceeded 3 W m^-2, even with higher surface stress.

A study of the boundary layer under fast ice near Resolute Bay NWT resulted in a manuscript (Crawford et al., 1998) which includes a description of the impact of advection of a horizontal density (salinity) gradient by tidal currents on turbulence scales and ice/water stress. At times when salinity decreased in the tidal cycle, both the turbulent length scale (determined from the vertical velocity spectrum) and the undersurface drag coefficient increased. The effect reversed during the part of the tidal cycle when salinity increased. In the latter case, denser water underruns lighter water near the surface because of boundary layer shear, tending to stabilize the boundary layer vertically. A significant feature of the study is that the undersurface of the first-year fast ice was hydraulically smooth, with an effective surface roughness several orders of magnitude smaller than typically associated with pack ice.

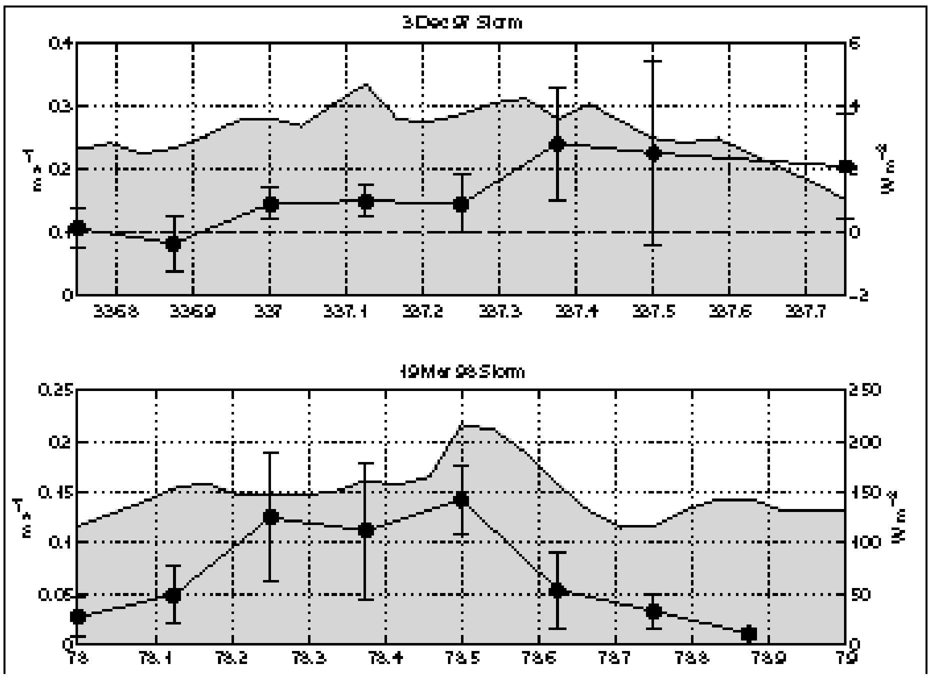

Figure 1. A. Current speed (measured relative to the drifting ice) and turbulent heat flux 4 m below the ice/water interface at the SHEBA drift station during a storm in early December, 1997. Heat flux is obtained from the zero-lag covariance of vertical velocity and water temperature. B. Same as A except during a storm in March, 1998, when the instrument mast was about 110 m downstream from a new pressure ridge. Note the difference in heat flux scales.

IMPACT/APPLICATION

Research into basic questions of how the ocean boundary layer works has wide application ranging from detailed studies of ice/ocean interaction to bottom boundary layer flow in estuarine environments to ocean parameterization in global circulation models. Relevant Naval programs include High Latitude Dynamics (Code 322HL), Ocean Modeling and Prediction Program (322OM), Physical Oceanography Program (Code 322 PO).

TRANSITIONS

Based on a recent analysis of summer ocean heat flux in the Arctic during the AIDJEX project (Maykut and McPhee, 1995), our ideas about the importance of summer insolation and heat storage in the Arctic mixed layer have been evolving rapidly. A major thrust of the SHEBA ocean program was to characterize the exchange of heat between the mixed layer and ice pack, and we now have a very extensive data set for addressing that problem. We also have a significant amount of upper ocean data covering a much wider swath of the Arctic from the SCICEX 98 submarine mission. We had hoped to get extensive measures of mixed layer temperature and salinity using the CTD in the sail of the USS Hawkbill; however, due to the late start of the cruise and the fact that the mixed layer depth was often less than the safe operating depth for the submarine, those data are quite limited. In looking at the preliminary (unedited) expendable conductivity-temperature-depth (XCTD) profiles, it appears that they may fill much of the data void (Fig. 2) by allowing us to estimate the heat content of the mixed layer over a wide region sampled by the submarine. Combining SHEBA turbulence measurements with SCICEX XCTDs provides one example of extending detailed ("process oriented") measurements to much wider scales and times using a variety of measuring platforms including unmanned data buoys and both manned and unmanned submersibles.

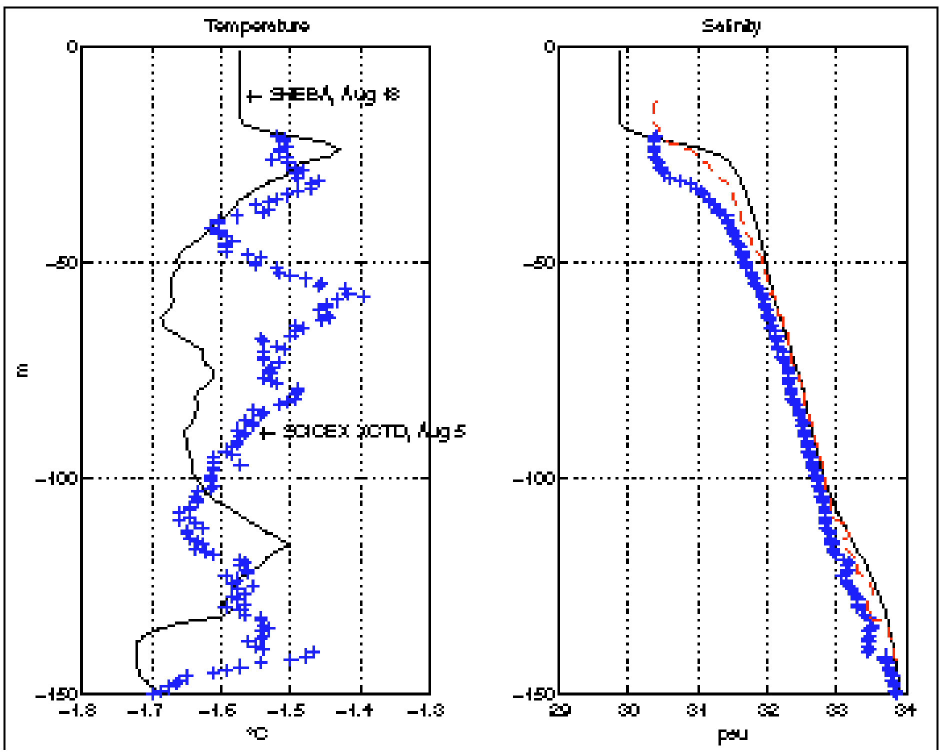

Figure 2. Comparison of upper ocean temperature and conductivity measured by XCTD from the USS Hawkbill on 5 Aug 98 and by the profiling CTD at ice station SHEBA 13 days later, when the station trajectory passed within about 7 km of the SCICEX location. Depth determination for the XCTD near the surface is problematic-- if the XCTD profile is raised by 8 m (dashed curve in salinity panel), there is quite good agreement. Temperature and salinity in the upper few meters of the XCTD casts may be used to estimate the elevation of mixed layer temperature above freezing, an important indicator of summer ocean heat flux.

RELATED PROJECTS

I am (i) working closely with co-PIs J. Morison, D. Martinson, and T. Stanton on SHEBA ocean physics analysis; (ii) collaborating with Morison on interpretation of summer lead data; (iii) working with G. Maykut on SCICEX estimates of heat content and ocean heat flux during the 1998 transect of the USS Hawkbill.

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